Technical science and innovation

Volume 2019 | Issue 2 Article 1

8-2-2019

DIAGNOSTIC ANALYSIS OF RANDOM VIBRATION RESULTS IN THE AVIATION GAS TURBINE ENGINES PULSE-WIDTH AUTOMATIC CONTROL SYSTEMS BASED ON DYNAMIC GRAPHS

G. Sh. Tuganov
Academy of Armed Forces of Uzbekistan

C. M. Rakhimov
Academy of Armed Forces of Uzbekistan

E. Norkulov
Aircraft and engine of aviation military school

UDC 621.431.75

DIAGNOSTIC ANALYSIS OF RANDOM VIBRATION RESULTS IN THE AVIATION GAS TURBINE ENGINES

G. Sh.Tuganov[1], C. M.Rakhimov[1], E.Norkulov[2]

[1]*Academy of Armed Forces of Uzbekistan*
[2]*Aircraft and engine of aviation military school*

Abstract

Studies are often conducted to minimize the effect of vibration on equipment and its mechanisms. Since the engine is the main driving force of all technical objects, vibration is one of the factors hindering its operation. With this in mind, this article investigated the random probability distribution of vibration parameters using the laws of mathematical statistical distribution and was found to be compatible with the normal distribution law. At the same time, this study demonstrates that the proposed method of technical diagnostics can be used to assess helicopter engine failures.

Key words: *gas turbine engine, vibration, normal distribution, correlation, selectivity, histogram, Pearson criterion, Romanovsky criterion, resource, RMS quadrature.*

The scientific results and its confirmation.

Occurring in gas turbine engines vibration random values call the the main lot *x*, for researching the characteristics of the engine will extract from it a choice *X*, is equal to the volume of *n* that is, *X*<*x*. Empirical distribution function (distribution function of the choice) *X* is called a function $F^*(x)$, which determines an event probability for each value of *X*. so, according to the description:

$$F^*(x) = \frac{n_x}{n} \qquad (1)$$

The number of variants is less than n_x –*x*;
n-is the volume of choice.

The *F (x)* integral distribution function of the main lot is different from the empirical function of the sample distribution, and it is called the theoretical distribution function. However, it follows from Bernoulli's theorem that $X<x$ is the relative frequency of a phenomenon, i.e. $F^*(x)$, probably approximates the probability *F(x)* of the same phenomenon [1-5].

In order to assess the theoretical function by choosing (sampling set) the main set (results of random vibration on the entire object under examination, i.e. on the helicopter engine) we use the results (9^{th} column of table 1,) research works conducted in the conditions of the Republic of Uzbekistan.

Table. 1.

Sample statistical data of diagnostic object

1	2	3	4	5	6	7	8	9	10
№ Engine	**снэ ч.**	**$P_н$**	**$T_{вх}$**	**$\approx \alpha$ мм**	**$\pi_к$**	**$n_{тк}$ ном. %**	**Тг ном. ^{0}C**	**ϑ I опора мм/с**	**ϑ IV опора мм/с**
right engine.	0	753,4	26	0,00	9,4	94,7	820	2	**22**
ТВ3-117ВМА	500	703	32	0,08	9,39	94,6	832	6	25,2
7896544921590	700	705	12,5	0,11	9,3	94,2	834	10	28,2

year of manufacture 1987 FO-2009 h, After repair 12.04.16 y. ALR-382 h/	900	710	27,5	0,13	9,25	94,1	835	14	28
	1203	708	26,2	0,17	9,2	94,0	838	18	29,5
	1409	697,4	28	0,20	9,17	93,8	856	22	31,82

FO (h)-first operation
ALR (h)-after last repairing

Table. 2.

Mi-8 helicopter engine statistical data of the distribution of vibration parameters

options X_i *мм/с*	2	6	10	14	18	22
number of measurements n_i (frequency)	6	12	14	18	24	26

Based on the data of table 1, we will build a table 2, where we find the sample size of observations equal to the total sum of frequencies in which the highest value of this parameter is 2,

$$6+12+14+18+24+26=100,$$

Then, there will be $F^*(x)=0$ at $X\leq 2$; there will also be $X_1= 2$ at $X<6$ and this will be repeated 6 times.
Thus, the interval of the empirical function arises:
If,

$$2<X\leq 6 \text{ then } F^*(x)=\frac{6}{100}=0{,}06\ ,$$

At a vibration value $X< 10$ then, events $X_1=2$ and $X_1=6$ will be 6+12=18 times observed.
Then,

$$\text{At } 6<X\leq 10 \text{ will be } F^*(x)=\frac{18}{100}=0{,}18.$$

When X<14 will be $X_1=2$, $x_2=6$, $X_3=10$, next, 6+12+14=32 times events are observed.
Based on the above:

$$\text{At } 10<X\leq 14 \text{ will be } F^*(x)=\frac{32}{100}=0{,}32\ ,$$

furthermore,

$$X\leq 18 \text{ is } 14 <X\leq 18 \text{ then } F^*(x)=50/100=0{,}5.$$

At $X= 22$ there will be the largest option, then At $X\leq 22$ based on the fourth property of the empirical function there will be $F^*(x) = 1$.

Now we write down the expression of the studied mathematical probability of the parameter distribution range characterizing the mechanical oscillations of the aircraft engines used in terrain of Uzbekistan:

$$F^*(x) = \begin{cases} X < 2 - \partial a \;\; 0 \\ 2 < X \le 6 - \partial a \;\; 0{,}06 \\ 6 < X \le 10 - \partial a \;\; 0{,}18 \\ 10 < X \le 14 - \partial a \;\; 0{,}32 \\ 14 < X \le 18 - \partial a \;\; 0{,}5 \\ 18 < X \le 22 - \partial a \;\; 1 \end{cases} \quad (2)$$

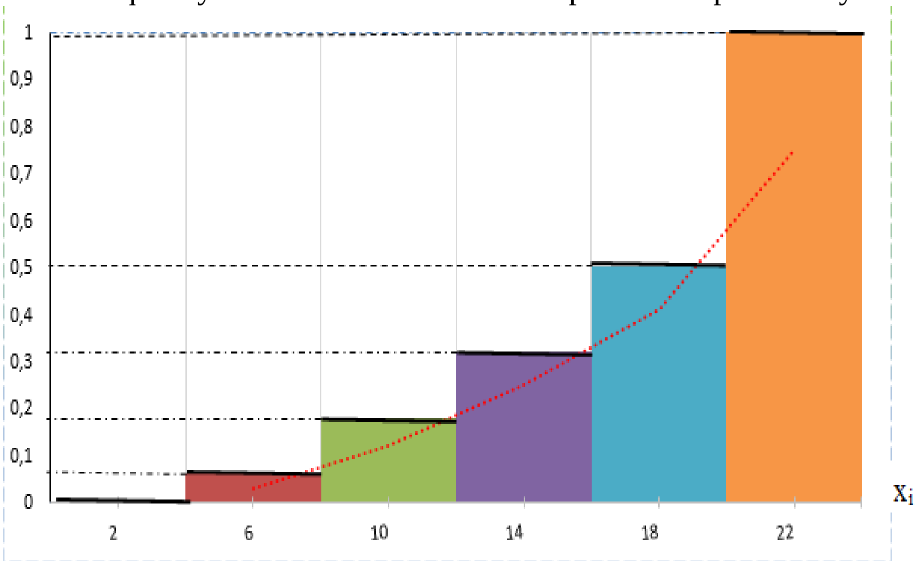
In (2) given the functional relationship, the function helps predict observation events (critical failures) of diagnostic objects (up to). Let's make table 3 on the basis of the same empirical function.

Table. 3.

Dependence of the empirical function on the probability of observations

options X_i *V- мм/с*	2	6	10	14	18	22
Values of empirical function of observable phenomena *P*	0	0,06	0,18	0,32	0,5	1

Dependence of the frequency of oscillations of the helicopter on the probability of observations



In the same place, the theoretical function values of *F(x)* are related to the empirical function and its probabilistically expected results [6-9]. Therefore, we can say that the empirical distribution function serves to evaluate the theoretical distribution function.

For mathematical processing of the received data it is necessary to make the table at first (table 4).

Generalities:

1.when constructing vibration values, the number of measurements or observations must be taken into account;

2.the vibration values are divided into ranges by an equal number of observations (total number of observations (50) [10-15].

Table. 4.

Statistical distribution of GTD helicopter vibration parameters

I	*[0-3]*	*[3-6]*	*[6-9]*	*9-12]*	*[12-15]*	*[15-18]*	*[18-21]*	*[21-24]*	*[24-27]*	*[27-30]*
n_x	*1*	*2*	*5*	*6*	*11*	*10*	*7*	*4*	*3*	*1*

Given the proximity of the distribution to the normal distribution in table 4, we make a histogram of the relative frequency of observations (Table 5). Then for convenience of calculation we will make the table of probabilities of distribution of vibration values

Table. 5.

Probable distribution of vibration values for histogram compilation

X	*1,5*	*4,5*	*7,5*	*10,5*	*13,5*	*16,5*	*19,5*	*22,5*	*25,5*	*28,5*
W	*0,02*	*0,04*	*0,1*	*0,12*	*0,22*	*0,2*	*0,14*	*0,08*	*0,06*	*0,02*

For processing of experimental results and convenience of calculation we accept the new variable t expressed by arithmetic progression, in arithmetic progression $a_1=1,5$, $d=3$ then, the general formula will look as follows:

$$x_n=a_1+d(n-1)=1,5+3(T-1)=3T-1,5 \tag{3}$$

Then we find the expectation.

$$M(T)=\sum_{i=1}^{10} T_i W_i, \tag{4}$$

To compose the table to expression (4), we enter statistical distributions in the first and in the second line, so as a result we calculate expectation:

$$M(T)=\sum_{i=1}^{10} T_i W_i = 0,02+0,08+0,30+0,48+1,10+1,20+0,98+0,64+0,54+0,2=5,54$$

Then we find the dispersion in vibration,

$$\sigma(X)=\sqrt{D(X)}=\sqrt{34,65}=5,88\approx 5,8 \tag{5}$$

where $\sigma(X)$ - the mean square deviation;
$M(X)$ - expectation;
$D(X)$ - the variance of the vibration.

If you received a smooth curve close to a Gaussian distribution, it is possible to treat statistically the data obtained for gas-dynamic engine parameters, using known mathematical expectation value $m=M(X)$ and standard deviation in vibration motor $\sigma=\sigma(X)$ for the normal distribution.

We see that the mathematical function of the deliverance corresponds to the normal distribution of the random variables are Gaussian.

Thus it can be observed that the expectation function corresponds to the normal distribution of random variables by Gauss,

$$f(x)=\frac{1}{\sigma\sqrt{2\pi}}\cdot exx^{-(x-15)^2/(2\sigma^2)}, \tag{6}$$

If we assume $\frac{x-15}{5,9}=U$ that regards to $f(x)$ the-Gauss function, we get that it is the vibration of the gas turbine engine (GTE) as the Gauss distribution for random variables of the GTE, Therefore, the results obtained can be compared with the probability of random variables falling into a given point. We assess this by the formula:

$$P(\alpha < (x) < b) = 0{,}5\left[\Phi\left(\frac{b-m}{\sigma\sqrt{2}}\right) - \Phi\left(\frac{\alpha - m}{\sigma\sqrt{2}}\right)\right], \quad (7)$$

in this case, enter the designation of the error function

$$\Phi(x) = \frac{2}{\sqrt{\kappa}}\int_0^x e^{-t^2}\, dt\ , \quad (8)$$

Then, the Laplace function whose values are given in table 4 [2], Find *m=M (x)=15* and the table data:

$$P(0 < x < 3) = 0{,}5[-\Phi(1{,}44) + \Phi(1{,}80)] = 0{,}5[-0{,}9583 + 0{,}9891] = 0{,}02;$$

Continuing thus, we find the probability of events at all intervals (table 1) vibration,

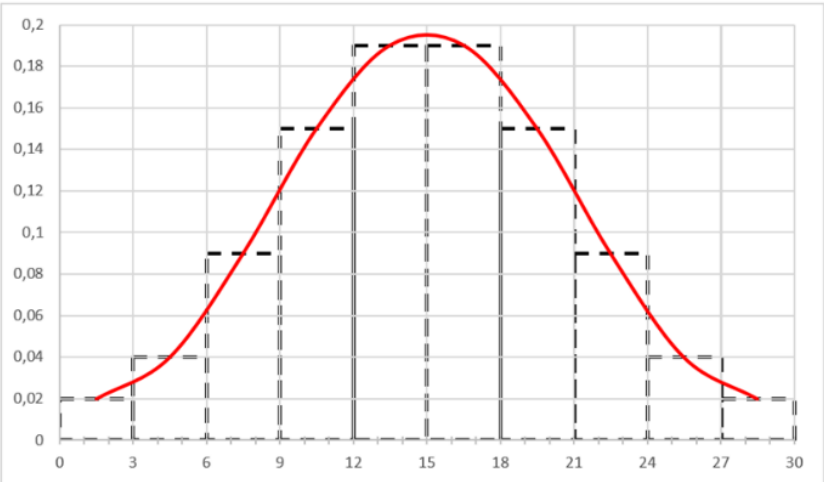
$$P(3 < x < 6) = 0{,}5[-\Phi(1{,}08) + \Phi(1{,}44)] = 0{,}04;$$

We will continue according to the table 1 and so take to the interval.

On their basis for the period of operation in mountain desert conditions of Uzbekistan we draw histogram 2 a normal distribution of vibration values.

Comparing the values of *W* and *h* × *f(x)* (or *W* and *P)*, we can verify that the statistical distribution of vibration data of complex technical systems, obtained by the example of the helicopter GTE [13, 14], corresponds to the normal distribution law.

Histogram 2



Histogram 2. Distribution of vibration data of MI-8 helicopter GTE in mountain-desert operating conditions at operating time 2000-2500 hours

Now calculate the random vibration values of the left engine of the helicopter №22565 1986 release. We use the table below to calculate χ^2:

Table. 4.

N	W	P	W-P	$(W-P)^2$	$\frac{(W-P)^2}{P}$

1	0,02	0,02	0	0	0
2	0,04	0,04	0	0	0
3	0,1	0,09	0,01	0,0001	0,001
4	0,12	0,15	-0,03	0,0009	0,006
5	0,22	0,19	0,03	0,0009	0,005
6	0,2	0,19	0,01	0,0001	0,0005
7	0,14	0,15	-0,01	0,0001	0,0007
8	0,08	0,09	-0,01	0,0001	0,001
9	0,06	0,04	0,02	0,0004	0,01
10	0,02	0,02	0		

Calculation table χ^2

Then we get:

$$\chi^2 = n\sum_{i=1}^{10}\frac{(W-P)^2}{P_i} = 50 \cdot 0{,}0242 = 1{,}21 \quad (9)$$

i=10 number of measurements;
t=3 step between measurements;
Then, $r = n_x - h = 10 - 3 = 7$
To calculate the criterion given in table IV, find the probability values *r=7* on the basis of the table if, $\chi^2 = 1$ then, *P*=0,9948; if, $\chi^2 = 2$ then, *P*=0,9598; if, $\chi^2 = 1{,}21$ then, for the interval *P*, a value is assumed.

The greater the number χ^2, the less likely the event is. This value can be found by interpolation.
For $\chi^2 = 1$ и $\chi^2 = 2$ the probability has the following difference:

$$\Delta P = 0{,}9948 - 0{,}9598 = 0{,}035$$

Increasing χ^2, decreases the value of *P* so $\chi^2 = 1{,}21$,
further based on this property

P(1,21)=0,9598+(2-1,21)0,035=0,9598+0,79·0,035=0,98745;

Conclusion

Since the probability obtained is greater than 0,1, according to Pearson's criterion, the statistical distribution obtained is close to the law of normal distribution.
According to Romanovsky criteria:

$$\left|\frac{\chi^2 - r}{\sqrt{2r}}\right| = \frac{|1{,}21-7|}{\sqrt{14}} = \frac{|5{,}79|}{3{,}742} = 1{,}547 < 3 \quad (10)$$

Thus, the agreement between the statistical distribution and the theoretical distribution can not always be observed, that is, when P <0,1 then, it is incompatible, and when P> 0,1 is consistent. In our case, the probability of the event is P> 0,1 and it is consistent.
Based on V.I. Romanovsky's criterion (10), if the modulus $\left|\frac{\chi^2 - r}{\sqrt{2r}}\right|$ is greater than or equal to 3, then, is probabilistically non-approximated and has a large difference, if less than or equal to, the values between the subs are approximate.

References

1. Mitchell J.S. From vibration measurements to condition based maintenance. seventy years of continuous. Sound and Vibration, Vol. 41, 2007, p. 62-78.
2. Dominiczak K, Rządkowski R, Radulski W, Szczepanik R. Online prediction of temperature and stress in steam turbine components using neural networks. J. Eng. Gas

Turbines Power. 2016; 138(5), ASME Paper No: GTP-15 1396. http://dx.doi.org/10.1115/1.40

3. Yang X, Pang S, Shen W, Lin X, Jiang K, Wang Y. Aero engine fault diagnosis using an optimized extreme learning machine. International Journal of Aerospace Engineering. 2016, Article ID 789287. http://dx.doi.org/10.1155/2016
4. Barkov A., Barkova N., Mitchell J. Condition assessment and life prediction of rolling element bearing. Sound and Vibration, Vol. 6, 1995, p. 10-17.
5. Robinson J. C., Canada R. G., Piety K. R. Peak Vue analysis – new methodology for bearing fault detection. Sound and Vibration, Vol. 30, 1996, p. 22-25.
6. Tuganov G.Sh., Begmatov Sh.A., *Osobennosti postroeniya diagnosticheskih ustroystv slozhnyih tehnicheskih sistem s elementami iskusstvennogo intellekta* [Features of construction of diagnostic devices of complex technical systems with elements of artificial intelligence]. Scientific and practical conference, -Tashkent №1, 2019, p. 63-68 (in Russian).
7. Vorobiev V.G., Konstantinov V.D. *Nadezhnost i tekhnicheskaya diagnostika aviacionnogo oborudovaniya* [Reliability and technical diagnostics of aviation equipment]: Textbook for universities.-Moscow: MGTU SA, 2010.-345 p (in Russian).
8. Vorobiev V.G., Konstantinov V.D. *Nadezhnost i tekhnicheskaya diagnostika aviacionnogo oborudovaniya* [Reliability and technical diagnostics of aviation equipment]: Textbook for universities.-Moscow: MGTU SA, 2010.-345 p (in Russian).
9. Gasior M., Gonzalez J. L. Improving FFT frequency measurement resolution by parabolic and gaussian spectrum interpolation. AIP Conference Proceedings, Vol. 732, 2004, p. 276.
10. Tuganov G.Sh. *Obosnovanie raschyota mest ustanovki sensorov pri diagnostirovanii tehnicheskogo sostoyaniya slozhnyih sistem vertoleta* [The rationale for calculating the installation locations of sensors in diagnosing the technical condition of complex helicopter systems]// scientific and practical conference -Tashkent: 2019. No 1 p. 106-111.
11. Grishchenko D. Automatic processing of narrow band vibration spectra of marine rotating equipment with the purpose to determine the parameters that are informative for the diagnostics. Marine Intelligent Technologies, Vol. 34, 2016, p. 8-13.
12. Hess, R., Duke, A., Kogut, D., “The IMD HUMS as a tool for rotorcraft health management and diagnostics”, Aerospace Conference-IEEE, Big Sky, Montana, March 2001.
13. N.N. Ishin, V.B. Algin *Osnovnye napravleniya razvitiya diagnostirovaniya transmissionnyh uzlov mashin* [Main directions of development of diagnostics of transmission units of cars]Journal “Mechanics of machines, mechanisms and materials”. 2014. № 2 (27) Pp. 12-22. (in Russian).
14. Arslanov R.V. *Problemy izmereniya i obrabotki parametrov vibracii gazoturbinnyh dvigatelej* [Problems of measurement and measurement-works of vibration parameters of gas turbine engines]. Problems of engineering and technology of Telecommunication: proceedings of the fourth international. science.-tech. Conf. Ufa: UGATU, 2003. Pp. 77-79. (in Russian).
15. Arslanov R.V. *Kontrol' parametrov vibracii gazoturbinnyh dvigateley v real'nom masshtabe vremeni* [Control of vibration parameters of gas turbine engines in real time] Arslanov control of vibration parameters of gas turbine engines in real time] journal “Vestnik UGATU”. - Ufa, 2011. No. 1 (41). Pp. 8-14 (in Russian).